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A METHOD OF INVESTIGATION OF THE STRENGTH IN BENING IN THE HORIZONTAL PLANE OF AN AFDB WHEN SUBJECTED TO LATERAL WIND, CURRENT, OR WAVE FORCES

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WALTER W. VANDERWOLK, JR.

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A METHOD OF INVESTIGATION of the STRENGTH IN BENDING IN THE HORIZONTAL PLANE of an AFDB WHEN SUBJECTED TO LATERAL WIND, CURRENT, OR WAVE FORCES

Submitted to the Faculty of
Rensselaer Polytechnic Institute
in partial fulfillment of the requirements
for the Degree of
Master of Civil Engineering

by

Edward M. Saunders
Walter W. VanderWolk, Jr.

Troy, New York
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INTRODUCTION

The conclusion of World War II in 1945 left the Navy Department with the problem of keeping large numbers of ships in caretaker status. Among the largest of these vessels are the battleship type floating drydocks, eight hundred and twenty-seven feet in length. Some of these docks are moored in typhoon areas and future operations may require the service of these vessels in areas where high wind velocities may be expected.

Past investigations of the mooring problem involving this type of floating structure have not been exhaustive, due to the complicated nature of the problem, and because the moorings used have proved adequate. There has been concern, however, as to the safety of these moorings under extreme conditions of wind and sea. The highest wind velocities experienced by a vessel of this type occurred during a storm with wind velocities variously reported from 70 to 90 miles per hour. In another storm with winds at 120 miles per hour, several docks of a smaller type were lost. The possibility of the loss of a larger dock, built at a cost of $30,000,000. points to the advisability of a more refined method of analysis.

The flexural strength of a large dock when subjected to lateral loads, such as those resulting from wind, current, or wave forces, has never been investigated, according to cognizant engineers of the Bureau of Yards

and Docks. The arrangement of the basic mooring system for these docks tends to cause bending moment, and resulting flexural stresses, under the action of these lateral loads.

The object of this study is to develop a method of determining the loads in the horizontal plane, calculating the resulting shears and moments and determining the approximate stresses resulting therefrom, having given the distribution of wind, current, or wave forces and having given a specific mooring plan. At the time of writing, the only available data on load distribution involve wind only. Studies at the David Taylor Model Basin at Washington, D. C. will produce further data on force distribution from model tests.

Since the reactions of the mooring chains are as important a part of the loading as the external forces on the system, a method of determining these reactions consistent with the actual physical conditions had to be devised.

APPLYING THE CATENARY TO THE PROBLEM

Any moored object, when subjected to a displacing force, moves in a direction determined by both the force itself and the restraining action of the mooring chains. This displacement causes the catenary of the mooring chain or chains to alter so as to provide an additional restraining force, and thereby restore equilibrium. With a small number of chains, the problem of evaluating the forces exerted by the chains would be simply solved by applying the mathematical equation of a catenary. However, the solution for a floating object held by a large number of chains, such as a floating drydock, requires special treatment.

Reference to the general plan, Figure 1, shows that the specific example used in this study is a ten section battleship type floating drydock moored by means of thirty two chains arranged in opposing pairs. An assumption of the analysis used to determine the chain reactions, to be discussed in a different section, is that the same deflection will be experienced by both chains in any one pair. That is, if the end of chain L-1, which is fastened to the dock, moves twenty feet

forward, the end of chain L-2 also moves twenty feet forward. If d-2 moves twenty feet to port, d-1 also moves twenty feet to port. This assumption, in effect, disregards the effect of rotation of the dock, which would cause different displacements in any one pair. The error caused varies as the versine of the angle of rotation, and for small angles the versine is nearly zero.

These pairs, then, may be considered to act as a unit. Each chain has its force-displacement characteristic, and the characteristics of the two chains may be combined to produce the characteristic for the pair. The basic formula of a catenary is:

$$y = \frac{H}{w}\left(\cosh \frac{wx}{H} - 1\right) \qquad (1)$$

from which,

$$s = \frac{H}{w} \sinh \frac{wx}{H} \qquad (2)$$

and

$$T = H + wy. \qquad (3)$$

where:

y is the vertical distance from the point where the tangent line to the chain is horizontal to the point in question,

H is the horizontal component of the tension at any point on the catenary,

w is weight per foot of the chain,

x is the horizontal distance from the point where the tangent line to the chain is horizontal to the point in question, and

T is the tension in the chain at the point y,

all expressed in consistent units.

If a force F be applied to the pair of catenarys shown in Fig. 2, they will deflect a distance x. The two catenaries have each a different horizontal component of tension and catenarys of different shapes.

If one of these catenaries be detached and a force-displacement characteristic found, that for the combination may also be found. Referring to Figure 2, a chain is laid on the bottom in y feet of water, and one end is brought to the surface. Position CD represents zero displacement and zero force in the horizontal. Position AB represents x displacement, x' abscissa of the catenary, and H horizontal force.

Let w be unity, causing the expression H/w to be simply H. Let the horizontal distance from the point on the catenary in question to the point where the tangent to the chain is horizontal be designated by x'

Then:

$$y = H(\cosh \frac{x'}{H} - 1) \qquad (4)$$

and

$$s = H \sinh \frac{x'}{H} \qquad (5)$$

and

$$T = H + y, \qquad (6)$$

from (1), (2), and (3). It is obvious that should w be other than unity, the equations (4), (5), and (6) may still be utilized, the final horizontal force and tension being the horizontal force and tension obtained by these equations multiplied by the weight of chain per foot.

To find values of x' and H, the following procedure is used:

1. Assign an arbitrary value to x'/H.
2. Determine H from $H = y/(\cosh x'/H - 1)$. y, the depth of water, is known.
3. Having H, determine x' from $x' = (x'/H)(H)$. This procedure is necessary because x'/H must be used as a type of parameter, $\cosh x'/H$ appearing in the expression.
4. Let AD be designated Δs. $s = y + \Delta s$, both sides of the equation representing the distance from the point B to the end of the chain. Therefore, Δs is equal to s less y, or:

   $$\Delta s = H(\sinh \frac{x'}{H} - (\cosh \frac{x'}{H} - 1)). \qquad (7)$$
5. From the figure, x may be found by taking Δs from x'.
6. T is H plus y.

These six steps may conveniently be arranged in a table, the procedure which is followed in the discussion. After the results are tabulated, they are plotted on a graph, horizontal force and tension against displacement of the upper end of the chain.

In order to obtain numerical results, y, the depth of water, must be established. Operating conditions for the type of dock studied require a minimum depth of eighty feet to allow submergence to receive the ship to be docked.[1] A depth of ninety feet has been selected for this discussion. Table 1 contains the computations for H and T in terms of x for this depth.

Discussion with engineers of the Bureau of Yards and Docks of the Navy Department indicated that a length of chain of seven hundred feet from the edge of the deck to the anchor would be a representative length used in a depth of ninety feet. That length is used in this discussion.

It will be observed that a value of x'/H of 0.259 gives a length of catenary of 2670x0.2619 = 699 feet. At this point, the chain is just ceasing to be tangent to the bottom. The origin of the curve will then no longer lie on the bottom, but will fall to some point below the bottom, and the relationships used are no longer true.

---

[1] Frederick R. Harris, Inc.,"Operating Manual, Battleship Dry Dock"

When this occurs in this case, x has a value of 82 feet. The geometry of the mooring is such that when the chain is in a straight line, giving H and T values infinite in size, x is 85 feet. Should the chain be infinite in length, the value of (x'/H) approaching zero, the x distance will be ninety feet.

Figure 4 shows horizontal force and tension plotted as a function of the x distance. The dotted curve from 82 to 90 feet is the curve obtained from the calculations. The solid curve from 82 to 85 feet is obtained by leaving the calculated curve at the 82 foot point with a curve tangent to the original curve at that point and asymptotically approaching infinity at 85 feet. Inspection of the curves will show that the possibility of error from this procedure is slight in the range 82 to 83 feet, considering the relative accuracy of points plotted in that steep portion of the curve.

When a mooring is laid in the field, an initial tension is put on the chains. This initial tension prevents the dock from drifting about within the mooring area. Experience in the field has shown that a tension of ten thousand pounds is attainable with the standard equipment used for mooring the vessel.

When two chains having the characteristic such as Figure 4 are connected to the dock to form a pair, Figure 3, the pair is exerting no force on the dock in the hori-

zontal direction, each chain has the same value of initial tension, since the horizontal forces exerted by each are equal and opposite, and the weight per foot of chain is the same for both chains. The tension existing in both chains of this system is the initial tension which is attainable in practice, about 10,000 pounds. In order to correlate this tension with the tension characteristic obtained for the chain weighing one pound per foot, the weight per foot of the chain under study must be determined. The chain for the standard mooring of this dock is 3" cast steel chain, which weighs 72.5 pounds per foot, submerged in sea water. If the chain weighing 72.5 has a tension of 9750 pounds, the chain weighing one pound per foot has a tension of 9750/72.5 = 134.5 pounds. Referring to Figure 4, horizontal displacement against tension and horizontal force for a single chain, a chain weighing one pound per foot with a tension of 134.5 pounds has a displacement of 42 feet. It follows that a chain weighing 72.5 pounds per foot with a tension of 9,750 pounds also has a displacement of 42 feet. Although the pair of two chains exerts no resultant horizontal force, each chain is displaced from the zero position a distance of 42 feet.

It is now possible to obtain the characteristic of this pair of chains. Referring to Figure 3, if the system is displaced x feet to the right, the chain A has a dis-

placement of 42 plus x feet, with a corresponding force H_1, and chain B has a displacement of 42 minus x feet, with a corresponding force H_2, read from the characteristic of one chain. The force, F, corresponding to this displacement is H_1 minus H_2. For example, when x equals 20 feet, chain A has a displacement of 62 feet, and chain B has a displacement of 22 feet; H for chain A is 183 pounds and H for chain B is 11.3 pounds. F for x equals 20 feet is 172 pounds.

In this manner, the data for Figure 5, the plot of horizontal force against displacement of a pair of chains weighing one pound per foot with an initial tension of 134.5 pounds in ninety feet of water, is obtained. At a displacement of 43 feet, chain A has a displacement of 85 feet, with a resulting horizontal force of infinite magnitude. Therefore, the curve approaches the 43 foot abscissa asymptotically. Table 2 shows the computation used in obtaining this curve.

The method used in finding chain reactions requires a plot of the first derivative of the horizontal force vs. displacement curve. This was obtained by measuring the slope of the curve and taking the tangent of the angle, multiplying by the scale of the plot.

Throughout the remainder of this discussion, the term "x" shall refer to displacement of pairs of chains, as shown in Figure 3, and not the displacement of a single chain, as shown in Figure 2.

THE WIND LOADING

It is intended that this method of analysis be adaptable to any type of horizontal loading, as long as that loading can be converted to transverse and longitudinal forces and yawing moment. There is the additional qualification, however, that the distribution of the load along the dock must be known. It might be assumed that the knowledge of the total forces might be sufficient to enable determination of the chain reactions, and therefore the moment produced in the dock structure; but it would be necessary in that case to assume an arbitrary load distribution in order to determine shear and bending moment in the dock. The wind distribution curves used in this study were adopted as the most representative available in the absence of actual experimental results.

It is anticipated that experimental data will be obtained in the future by the Bureau of Yards and Docks, which will provide more accurate load distribution curves for wind and current forces. The wind pressure distribution curves of Figure 6 were obtained after consultation with Mr. A. Amirikian of the Bureau of Yards and Docks. They represent the aggregate results of several years of extensive research by Mr. Amirikian, and they are considered the most reliable curves available.

In order to utilize the pressure distribution curves, the following assumptions were made. They can be better visualized with the aid of Figure 1:

1. A dock length of 827 feet, divided into 10 equal sections of 82.7 feet. The nine 3-foot splices between sections were considered as integral parts of the ten 80-foot sections.

2. A dock draft of 8 feet, giving 20 feet of freeboard. This condition is considered to be normal with no ship in the dock.

3. Effective areas for outboard and inboard sides of the wingwalls were computed as follows:

Outboard:

Height: 20 feet freeboard + 56 feet wingwall $= 76$ feet.

Length: 827 feet

Area: $76 \times 827 = 62852$ feet^2

Inboard:

Height: 56 feet

Length: 827 feet

Area: $56 \times 827 = 46312$ feet^2

4. Effective area for the longitudinal forces was computed as follows:

Wingwall height: 56 feet

Wingwall width: 20 feet

Area per wingwall: 1120 feet^2

Section width: 256 feet

Freeboard: 20 feet

Area: 5120 feet^2

Total area: $5120 + (2 \times 1120) = 7360$ feet^2

5. The effective side areas were assumed to be the projected areas, since it is manifestly impossible to take into account the slight irregularities of the ends of the individual sections.

In order to evaluate the forces, the following formula was also supplied by Mr. Amirikian:

$$P = .00256\ V^2\ pA$$

where

P = the force in pounds

V = the wind velocity in miles per hour

p = the ordinate of the wind pressure distribution curve obtained by approximate integration over the area

A = the area in square feet

For the purpose of this study, a wind velocity of 120 miles per hour was chosen. It is considered that this is the highest constant wind which could be encountered, even though some gusts might be of momentarily greater velocity.

The values of p were obtained by approximate integration by rectangles, with the ordinates read at the center of each of the ten sections. The lever arms were

measured from the center of moments to the center of the section under consideration. The center of moments was taken at the center of the first windward section. The results are tabulated in Tables 3 and 4.

Definition of the column headings in these tables may aid in following the method of computation. In Table 3, they are as follows:

1. Wind angle - The acute angle made by the wind with the longitudinal axis of the dock.
2. Side - Side 1 represents the outboard windward surface, Side 2 represents the inboard surface of the windward wingwall, Side 3 the inboard surface of the leeward wingwall, and Side 4 the outboard surface of the leeward wingwall.
3. Section - The number of the section, numbering from the "bow". The "bow" will be taken as the end against which the wind is blowing.
4. p - The ordinate of the wind pressure distribution curve as previously defined.
5. Number of Sections - The number of sections from the bow section, containing the center of moments, and the section considered.

6. m - The moment of the p ordinate expressed in terms of number of sections contained in the lever arm.

7. Σp - The summation of p over 10 sections.

8. y_b - The resultant lever arm of Σp, expressed in number of sections from the center of the bow section.

9. $\bar{y}$ - The resultant lever arm of Σp, expressed in number of sections from the center of the entire dock, i.e., between sections 5 and 6.

The column headings of Table 4 are as follows:

1. Wind angle - As defined above.

2. Force name - Transverse, longitudinal, or moment.

3. Side - As defined above.

4. Σp - As defined above.

5. A - The area of the entire side under consideration.

6. $\bar{y}$ - As defined above.

7. pA or $pA\bar{y}$ - For transverse and longitudinal forces, pA equals the product of $\frac{\Sigma p}{10}$ x the total side area. For moments, $pA\bar{y}$ equals $\frac{p}{10} \times A \times \bar{y} \times 82.7$.

8. Total - The sum of the forces on the sides or pairs of sides, from column 7.

9. p - The force, equal to column 8 x .00256 v^2.

The forces resulting from a wind at 45° to the longitudinal axis of the dock were chosen for this study since

they represented the worst combination of transverse force and moment. As can be seen from comparison of the results at 30°, 45°, and 60°, neither the transverse force nor the moment at 45° are the largest values obtained; the largest moment occurs at 30° with the smallest of the three transverse forces, and vice versa at 60°. The condition at 45° was therefore considered the most critical of the known conditions.

In order to determine shear and bending moment at any section, it was convenient to also express the wind loads as a concentration upon each section. These forces were computed in accordance with previous assumptions and are tabulated in Table 5. The column headings are as before, with the exception of the following:

p_s - Total ordinate per section for pairs of sides with equal areas.

A_s - Side areas per section.

P_s - Force on the section.

DETERMINATION OF CHAIN REACTIONS

Methods previously used to determine chain reactions on floating drydocks are as follows:

1. Given lateral force, longitudinal force, and moment, the formula $\frac{P}{A} + \frac{Mc}{I}$ is used, as described by Frederick R. Harris, Inc., "Design Assumptions, Floating DryDocks", where P is the lateral force, A is the number of chains in the two quadrants resisting the moment, M is the moment, c is the distance to the chain at the greatest distance from amidships, and I is the sum of the second moments of the chains in the two quadrants resisting the moment. The result is an approximation of the horizontal force in the most highly stressed chain. This formula is acceptable for short docks only.

2. A trial and error method has been used. The effect of lee chains is disregarded. A plot of horizontal force against displacement, similar to Figure 4, is used. A trial and error solution is used to obtain equilibrium, an assumption of dock position being made, which determines the displacement of all chains, and the force exerted by each. If these forces do not produce equilibrium, another assumption of dock position must be made. This method was rejected both because the lee chains were neglected, and because of the difficulty of obtaining accurate results. It will be observed that an error in position of as little as 0.1 feet will produce a very large change in chain reaction.

3. A letter to the Bureau of Yards and Docks from the field outlined a method which consisted of determining the total wind force against the projected broadside area and dividing by the number of pairs of chains. The result is an approximation of the horizontal force in one chain. The method is decidedly inferior, as the effect of moment caused by the wind is disregarded, and the effect of the catenary relationship is not included.

4. Frederick R. Harris, Inc., Consulting Engineers, New York City, designers of the AFD3, used a method involving the use of indeterminate analysis combined with the catenary relationship which is not in print, nor available at the Bureau of Yards and Docks. This method is mentioned in "Design Assumptions and Methods, Floating DryDocks", by Frederick R. Harris.

Considering the inadequacy of the first three methods mentioned, and the unavailability of the fourth, it is necessary to develop a method of analysis which utilizes the catenary characteristics of the pairs of chains used in the mooring, which achieves equilibrium with a high degree of accuracy, and which evolves a definite answer without laborious trial and error.

The method used is an approximation and correction process. The process proceeds in steps; first the lateral and longitudinal forces are applied alone, the resulting displacements are found, an increment of displacement

necessary to produce the proper moment is introduced, and the resulting chain forces are found, with their respective displacements. To these displacements an increment of displacement is added to restore the proper transverse and lateral forces. Then another correction for moment is applied, the process being carried on in this way until the error is reduced to acceptable proportions. Experience shows that about six approximations gives about 0.5% error in equilibrium.

A complete description of the method follows.

Assumptions:

1. The dock is rigid and does not deflect transversely.

2. The effect of dock rotation on the distance between the chains of any one pair is negligible.

3. All chains are as described in the discussion of the catenary, that is, 700 feet long, in 90 feet of water, weigh 72.5 pounds per foot submerged in sea water, have 9750 pounds initial tension, and are laid either perpendicular to or parallel with the center line of the dock.

4. As the dock moves in a direction perpendicular to the line of a chain, thus swinging the chain through a slight arc, the effect of the change of the line of action of the chain is negligible.

5. There is no vertical movement of the dock.

6. The anchors do not drag.

7. There is no elastic elongation of the chains.

Definitions:

a-1, a-2, etc., - Chain designation, as shown in Fig. 1.

P - An external force, either transverse or longitudinal.

F_n - The horizontal force in a pair of chains resulting from the nth approximation.

x_n - The displacement of a pair of chains as a result of the nth approximation.

$f'(x_n)$ - The first derivative of F with respect to x for the value of x_n existing as a result of the nth approximation.

Delta x_n - The correction to be added to x_n to give the value of x for the next approximation.

M_n - The moment about the center produced by a pair of chains in the nth approximation.

Delta M_n - The correction to be added to M_n which restores equilibrium with the external moment.

y - The distance from the center of the dock to the point where the chain, or pair of chains, are fastened to the dock, measured along the axis of the dock which is perpendicular to the line of the chain.

$\Sigma \Delta M$ - The sum of the increments of moment in all the chains to restore equilibrium. $\Sigma \Delta M$ = Sum of Delta M_n.

Referring to Figure 7, if the force P alone is applied to the dock, each chain has the force $F_1 = P/N$, where N is the number of pairs of chains capable of resisting the force. Where P is lateral force, N is 14. Where P is longitudinal force, N is 2. Discussing only lateral effects, as in Figure 7, reading F_1 on the characteristic for a pair of chains, x is found, and the position of the dock is defined as position 1. It is desired to determine a correction to apply to x_1 such that the dock may be rotated to position 2, in which position the moment produced by the chain reactions will equal the moment applied externally. For this step, the assumption is made that the moment exerted by the chains at either end of the dock is negligible.

Considering the transverse chains only:

$$\Sigma \Delta M = M_e = \Sigma M_n = \Sigma y(F_2), \qquad (1)$$

$$= \Sigma y(F_1 + \Delta F) \text{ to satisfy equilibrium}$$

Therefore $M_e = \Sigma y \Delta F$, since y has equal plus and minus values (2)

But $f'(x) = dF/dx \simeq \Delta F/\Delta x$

Therefore $\Delta F = \Delta x \cdot f'(x)$, approximately. (3)

Substituting (3) in (2),

$$M = \Sigma(y \cdot \Delta x \cdot f'(x)). \qquad (4)$$

But, by similar triangles,

$$\frac{\Delta x}{y} = \frac{\Delta x_a}{y_a} \qquad \text{or,}$$

$$\Delta x = \frac{y \cdot \Delta x_a}{y_a} \tag{5}$$

Substituting (5) in (4),

$$M = \sum \left[\frac{(y^2 \cdot \Delta x_a \cdot f'(x)}{y_a} \right]$$

Factoring constants,

$$M = \frac{f'(x) \cdot \Delta x_a \cdot \sum y^2}{y_a} \tag{6}$$

Or,

$$\Delta x_a = \frac{M \cdot y_a}{f'(x) \cdot \sum y^2} \tag{7}$$

In equation (6), Δx_a is the only unknown. When Δx_a has been found, the remaining increments of displacement may be found from Δx_a by applying ratios of distance from the center of the dock. The corresponding forces are read from the characteristic curve.

The dock now occupies position 2. Correction for the effect of moment has been made to the first position resulting from pure transverse force, and the correction has caused a resulting error in trnasverse force. The next step consists of correcting this error in transverse force, and to also correct the longitudinal force which was disturbed by the last operation.

Factoring,

$$\Sigma \Delta M = \frac{\Delta x_a \Sigma y^2 \cdot f'(x)}{y_a}$$

From which,

$$\Delta x_a = \frac{\Sigma \Delta M \cdot y_a}{\Sigma (y^2 \cdot f'(x))} \tag{14}$$

The process is repeated using relationships (10) and (14) until results are obtained within the desired accuracy.

Table 6 demonstrates the process for the example used. Column 2 gives the total force divided by the number of chains, which is the load carried by each of the chains when pure force is applied. Column 3 gives the value of x for this value of F. Column 4 tabulates f'(x). Column 5 contains Δx as found by equation (7). Column 6 is column 3 plus column 5. In column 7 are recorded the forces corresponding to the value of x in column 6. Column 9 is the corrective increment of x found from equation (10) above. Column 13 is column 11 multiplied by column 12. The total of column 13, when subtracted from the external moment, gives the value of sigma delta M, used in equation (14) to find the values in column 17. The sum of column 16, the values entered there being column 15 multiplied by column 14, is also substituted in equation (14). Columns including column 18 and beyond repeat columns 6 through 17.

In the example at hand, the increments of x reduce themselves to 0.02 feet or less when finding the sixth approximation. Had the points plotted on the graph been

absolutely correct, and not estimated in the range from 40 to 43 feet, reading of the graph with the scale used would still have doubtful accuracy with values of x expressed to 0.02 feet or less, and the values of force have an accuracy of plus or minus 10 pounds. It is, therefore, not necessary to carry the process further.

It will be noted that the final values of F and M are correct to 0.5%. It does not follow necessarily that the value of force found for each pair of chains is within 0.5% of the force that would exist had the actual conditions used been exactly duplicated and the forces measured. Errors in the graph used, human error in reading the graph, and the limitations of the slide rule eliminate the possibility of accuracy of as high a degree as 99.5%. The answers to the mooring problem are recorded to this high apparent accuracy in order that a condition as near as possible to complete equilibrium is established, and the shear and moment values to be developed later will not show an error in equilibrium. Should the value of x measured from an actual prototype situation differ as much as a foot, or more, it is evident that the distribution of forces along the length of the dock follows closely the distribution of forces to be found in an actual catenary, since the forces are plotted on a smooth curve which may be displaced right or left slightly from its true position, but which gives a good representation of the values of the forces in the chains one relative to another. If these values of chain forces,

accurate relative one to another, give equilibrium, then the values of the forces individually must also be accurate.

After the problem undertaken in this work became known to an engineer in the Bureau of Yards and Docks who had formerly had experience in the suspension bridge field, he transmitted to the authors a set of formulas defining the catenary. Like many formulas used in engineering practice, they are not considered to be generally known. They are not used in the analysis as presented herein, but they are presented as a possible means of obtaining values of the characteristic curves in the doubtful region where the chain does not lie tangent to the bottom. They will be used as a check on the highest chain reaction to ascertain the error in the characteristic curve as used.

$$s = \frac{H}{w} (\tan A - \tan B)$$

$$y = \frac{H}{w} (\sec A - \sec B)$$

$$x = \frac{H}{w} \log_n \frac{(\tan (45^\circ + A/2))}{(\tan (45^\circ + B/2))} .$$

Where:

s	-	the length of chain involved in the catenary.
y	-	the length of the vertical projection of the catenary.
x	-	the length of the horizontal projection .
H	-	the horizontal force at any point in the chain.
w	-	the weight per foot of the chain.
A	-	the acute angle the tangent to the curve at the point (x, y) makes with the horizontal.
B	-	the acute angle the tangent to the curve at the point (0, 0) makes with the horizontal.

The accurate use of these formulas requires the use of six or seven place tables or a calculating machine. The choice of variables affects the usefulness of the formulas. If s, x, and y are fixed, and it is desired to find H/w, a triple trial and error method of solution must be used, a process which, it is believed, could require the use of an electronic calculating machine. If s, y, and H/w are fixed, it being desired to determine x, a double trial and error method must be used which is comparatively simple of solution.

The value found for chain a-1 by Table 6 will be checked by the use of these formulas. The chain has a displacement of 41.45 feet. Therefore x for the chain is 41.45 + 42.00 + 610.00 = 683.45 feet. The comparison will be made between this x value of 683.45 and the value of x obtained from the formulas when y, s, and H/w are fixed.

$$y = (H/w)\,(\sec A - \sec B) \qquad 90 = 5040\,(\sec A - \sec B)$$

$$s = (H/w)\,(\tan A - \tan B) \qquad 700 = 5040\,(\tan A - \tan B)$$

Solution by trial and error gives $A = 11^\circ\ 16.33'$, $B = 3^\circ\ 27.45'$, within accuracy of five place trigonometric and logarithm tables.

$$x = (H/w)\,\log_n \frac{(\tan\,(45^\circ + A/2))}{(\tan\,(45^\circ + B/2))}$$

$$= 5040 \cdot 2.30258 \cdot \log_{10} \frac{(\tan\ 50^\circ\ 38.17')}{(\tan\ 46^\circ\ 43.72')}$$

tan 50-38.17	log	.08600		
tan 46-43.72	log	.02622		
		.05978	log	8.77656-10
		2.30258	log	.36222
		5040	log	3.70243
		693.77	sum	2.84121

The actual computations for this step are given in order to demonstrate that five place tables are insufficient for accurate results to five significant figures. The log term, 0.05978, sensitive as it is to slight errors in angle, and existing as it does in four significant figures, reduces the answer to accuracy of four significant figures or less. The value 693.77 differs from the value 693.45 obtained by the analysis by 0.3 feet. This indicates that the characteristic curve used has a shape closely approximating the correct shape, and that the values of chain reactions are accurate, one with respect to the other.

The solution above yields the angle the chain makes with the horizontal at its upper end. Since $T = H \sec A$, and the actual horizontal force is $5040 \cdot 72.5 = 365500$ pounds, the tension in the chain is $365500 \sec 11^\circ 16' = 365500 \cdot 1.0197 = 372000$ pounds.

Reference to Figure 4, the characteristic for one chain, shows that a chain with $x = 42 - 41.45 = 0.55$ feet exerts a negligible force, and therefore, substantially all the horizontal force is taken by chain a-1. Accordingly, that horizontal force may be all attributed to chain a-1 in computing the tension.

THE LOADED STRUCTURE

The type of floating drydock under study does not lend itself to ease of stress analysis. Structurally, the dock consists of two continuous wing walls, 20' x 55', placed 160' apart center to center, on edge, to the bottoms of which are bolted ten pontoon sections, each covering 80' of wingwall length, there being 3' between each pontoon and the next. The bolted connection consists of 408 1-1/4" bolts, 204 at each wingwall, in slotted holes. The holes in the wingwall are slotted fore and aft and the holes in the pontoon are slotted transversely, the theory being that deflections and strains will not be transmitted by the connection. The whole structure as described is 827' in length.

Although structurally the wingwalls are continuous, they actually consist of ten pairs of sections carried by their respective pontoon sections in a folded position to the erection site, where the wingwalls are raised, and the wingwalls of adjacent sections are welded together by means of a splice three feet long. The cross sections of a splice, and of a wingwall, are shown in Figure 8.

The designers of this dock, Frederick R. Harris, Inc., computed the moment of inertia of these sections about the horizontal axis as a part of their design. The moment of inertia about the vertical axis was not computed by the designers. The computation for this moment of inertia is shown in Table 7.

When the wind and chain loads already found are applied to the dock, the resisting action is very complex. The wind loads are applied largely as a distributed load on the wingwalls. The chain loads are introduced at the pontoon deck level, and are transmitted through the bolted connection to the wingwall. If this loading situation is viewed in cross section, the wingwalls will act as cantilevers, and the pontoon section will act as a beam with moment introduced by the two wingwalls.

The wind loads applied on the wingwall vary along the length of the dock, as do the loads introduced to the wingwalls from the chains through the bolted connection. The various cantilevers in various cross sections will have different loadings, and therefore torsion must exist along the longitudinal axes of the wingwalls.

The variation in loading along the dock will produce shears and moments in the wingwalls, considered to act as simple beams.

Should any degree of restraint exist in the bolted connection through bolt head friction, the pontoon, acting as a very deep beam, will aid the wingwalls in resisting bending moment.

The principal actions performed by the dock in following nature's law of least work in absorbing the loading into the dock structure are, therefore:

1. Wingwall cantilever action, and pontoon beam action.
2. Wingwall torsion
3. Wingwall bending

4. Pontoon bending as a deep beam.

Wingwall cantilever action and wingwall torsion are disregarded for purposes of determining stress since the magnitude of the loading caused by the wind is a small fraction of the loadings used in the analysis of the dock under critical design conditions. Had the loadings been appreciable, and the analysis proven necessary, that analysis would be worthy of separate study. The problem is complicated by the unknown rigidity of the joint between the wingwall and pontoon. The connection contains a rubber gasket which prevents rigidity. Loading distribution vertically as well as longitudinally would have to be known.

Wingwall bending is considered to be the principal action. Pontoon bending may be considered to be negligible because of the probability of bolt head slippage which would prevent the pontoon sections from aiding the wingwalls in resisting bending. (Local stresses do exist in the pontoon as a result of transmitting chain loads to the wing wall, but the distribution of loading is unknown. The stresses would be small, if determined, since the loads are small and the beam is very deep.

The stresses in flexure of the wingwall are analyzed under the following assumptions:

1. The bolted connection and pontoon form a rigid foundation such that the connection resists all torsion which may develop as a result of loading the wingwall beam eccentrically. Therefore, the wingwall will act as a

simple beam, all loads upon which may be assumed to act through the point of zero torsion, or the torsion center.

2. The bolted connection has absolute freedom of movement within the slots so that no bending is resisted by the pontoon.

3. The chain loads are transmitted to the wingwall by means of the bolted connection. The transfer is undoubtedly performed by distributed bearing, but for ease in computation, and considering the number of chain loads (14), approaching a distributed loading condition, the chain loads are assumed to be applied at points on the wingwall adjacent to the points where the chains are connected to the pontoon deck.

4. Although the wind loadings on the two wingwalls are different, the fact that the two wingwalls are pinned together, so to speak, by the ten pontoon sections, causing one wingwall to have the same deflection in bending as the other, gives the assumption that the bending is resisted half by one wingwall and half by the other.

The sum and substance of these assumptions, stated simply, is that the wingwalls act as simple beams, loaded with the wind and chain loads already determined.

Table 8, Wingwall Moments and Shears, gives the values of moment and shear at every load point. The maximum moment is 110,520 foot kips, which gives a stress of 55260x10/95889 = 5.76 ksi., half the moment being taken by each wingwall.

The moment at both ends should be 950 foot-kips. The discrepancy of 4495 foot kips at one end may seen excessively large, but it must be noticed that shear, one source of error, has a discrepancy of 7.9 kips, within 0.5% of Equilibrium. Should there be no error in moment due to lack of equilibrium in moment, the error which 7.9 kips could produce, should it be active for the whole length of the beam, would be 7.9x779.0 = 6150 foot kips, which is greater than the error involved. The reason for attempting to obtain equilibrium to 0.5% or better, although individual chain forces might have a greater error, is now evident.

It is also possible to approximate shear stress in the wing wall splice. Considering the splice cross section, it is evident that since the shear loading is introduced in the plane of the bottom splice plates, substantially all the shear resistance will be taken in these plates. The side plates will yield in bending. The top plates will yield in bending as a result of torsion. The splice taken as a whole will resist a scissors action, the pivot being at the top deck.

The maximum shear between sections is between sections 3 and 4, 720 kips. The area of the bottom plates is 480 sq. in. The stress is therefore 720/480 = 1.5 ksi.

CONCLUSIONS AND RECOMMENDATIONS

The chain reactions, bending moments, shears, and stresses obtained in the preceding sections were found by a new method which is believed to follow the actual physical conditions of the problems with sufficient accuracy to yield results with acceptable accuracy. The basis of the method is original, but an effort was made, as far as possible, to utilize knowledge gained in the few previous attempts to analyze this problem, and any other problems having bearing on the one at hand.

No attempt is made to state as a definite conclusion whether or not the mooring would fail under a load caused by a wind of 120 miles per hour, or whether or not the stresses resulting would be excessive. In the example at hand, certain conclusions are reached, which are valid under the assumptions used. It must be realized that different conditions of the problem, caused by changing one or more of the variables, such as chain length, chain weight, depth of water, dock freeboard, mooring plan, wind velocity, initial chain tension, or dock length, or by the inclusion of other forces, such as current, wave, or inertia forces, would require a separate analysis following the method outlined. The numerical conclusions, therefore, cover only the given case, and are included in order to demonstrate the results which may be reached by use of the method.

The horizontal force exerted by the maximum chain is 365500 pounds, with a corresponding tension of 372000 pounds. The standard mooring consists of 3" cast steel chain, connected to a 30,000 pound stockless steel[1] anchor. The proof load of 3" chain is 495,000 pounds.[2] The working load, by Bureau of Yards and Docks practice, is taken as 35% of the breaking strength. The working load for 3" chain is therefore 242,000 pounds, which indicates that a 3" chain is insufficient for this loading. The breaking strength of a chain required to carry 372000 pounds is 1062000 pounds, based on 35% loading. A 3-7/8" chain has a breaking load of 1110210 pounds.

To carry the process to completion, the analysis should be repeated using a chain having the weight per foot of a 3-7/8" chain.

The 30000 pound anchor used is capable of carrying a horizontal force of 213000 pounds, based on the convention that a stockless anchor will hold 7.1 times its weight in a sandy bottom.[2] This anchor is not sufficient to carry the load. Although the anchor choice should be made after substituting the 3-78" chain, in the analysis, or any further substitutions, should the 3-7/8" chain not prove satisfactory, the anchor choice, for sake of example, will be made on the basis of the forces found in the example used. The weight of the anchor required (7.1 divided into

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[1] Frederick R. Harris, Inc. "Operating Manual, Battleship Floating DryDock"

[2] Navy Department, "Mooring Manual"

the horizontal force) would be 52000 pounds.

The maximum flexural stress exists in the splice between sections 5 and 6, in the side plates of the splice. The value of this stress is 5760 psi. In itself, this stress is small, but it may be added to stress caused by other loadings on the structure, such as hogging or sagging.

The maximum shear stress exists in the splice between sections 3 and 4, in the bottom plates of the splice. The value of this stress is 1500 psi. Again, this stress is small, but may be additive to other stresses.

The procedure followed was outlined before work was started. As the analysis of the example taken progressed, certain improvements appeared advisable. Those that were anticipated were, of course, incorporated in the analysis, and are not included in this section. Those that became evident after completion of the various phases of the analysis are presented here for future use.

The use of the catenary equations as applied to suspension bridges for the portion of the catenary characteristic where the chain is not tangent to the bottom is recommended. It is suggested that x, y, and H/w be established and the corresponding x found.

The catenary curves were drawn with the use of four place tables and ten inch slide rule. Although the points found formed a smooth curve, it is recommended that tables of higher accuracy be used in conjunction with a calculating

machine in finding points on the curve.

It may be pointed out that families of curves for different depths and different values of initial tension could be drawn, available for solution of any particular problem. These curves might well be made on the basis of a chain weight of unity as used in this analysis. It is to be noticed that for initial tension of moderate value, the effect of the lee chains is small. This should not be taken as a general law, as high values of initial tension would cause the lee chains to affect the problem appreciably.

The results of the analysis can be no better than the loading used. The application of this method would be more practical after pressure and load distributions of wind, current and wave forces have been determined which have been established as accurate. The stresses and chain loads found will undoubtedly be larger when combined wind, current, and wave loads are applied.

If a more refined method of stress computation were desired in any future use of the method, it is suggested that a more refined system of loading be used, distributing wind loads as they actually occur, and taking into account the distribution of chain reactions from pontoon to wingwall through the bolted connection.

A more refined analysis would require the consideration of the deflection of the dock under the applied loading. This deflection in itself would change the loading by modifying the chain displacement by a small, yet appreciable,

amount. A possible general method of accomplishing this process would be to find the loads assuming a rigid dock, find the deflection of the dock caused by this loading, change chain reactions accordingly, and repeat the process until error is reduced to zero.

For an exact analysis, the effect of chain elasticity should be taken into account. The load carried by a chain causes elongation of the chain, and correction would have to be made to the characteristic curve of the catenary to account for the greater length of chain.

Involved in a complete analysis of the structural problem would be an analysis of local stresses around the point of connection of the mooring chain to the dock. Failure at this point would be equally as serious as failure of a chain, and much more serious than the dragging of an anchor.

Refined analysis would include a complete analysis of the work of the structure in resisting the applied loads. The major types of action have been enumerated, and the analysis could include many more types, limited only by the designer's imagination and the value of indeterminate structural analysis.

TABLE 1

1 $\frac{x}{H}$	2 cosh-1	3 $H=\frac{90}{\cosh-1}$	4 $x=\frac{x}{H}\times H$	5 Sinh	6 Sinh-(cosh-1)	7 $\Delta s = H\times 6$	8 $x' = x - \Delta s$	9 $T = H + y$
6.0	200.72	.448	2.69	201.71	0.99	.444	2.25	90.448
5.0	73.210	1.230	6.15	74.203	0.993	1.22	4.93	91.22
4.0	26.308	3.422	13.70	27.290	0.982	3.36	10.34	93.422
3.5	15.573	5.78	20.22	16.543	0.970	5.60	14.62	95.78
3.3	12.575	7.16	23.61	13.538	0.963	6.89	16.72	97.16
3.0	9.068	9.93	29.80	10.018	0.950	9.43	20.37	99.93
2.7	6.4735	13.90	37.55	7.4063	0.933	12.98	24.57	103.90
2.4	4.5569	19.72	47.35	5.4662	0.909	17.93	29.42	109.72
2.2	3.5679	25.22	55.50	4.4571	0.889	22.40	33.10	115.22
2.0	2.7622	32.58	65.16	3.6269	0.865	28.15	37.01	122.58
1.8	2.1075	42.70	76.90	2.9422	0.8347	35.60	41.30	132.70
1.6	1.5775	57.10	91.30	2.3756	0.7981	45.55	45.75	147.10
1.4	1.1509	78.15	109.30	1.9043	0.7534	58.80	50.50	168.15
1.2	0.8107	111.00	133.20	1.5095	0.6988	77.55	55.65	201.00
1.0	0.5431	165.80	165.80	1.1752	0.6321	104.80	61.00	255.80
0.8	0.3374	266.50	213.20	0.8881	0.5507	146.90	66.30	356.50
0.7	0.2552	353.00	247.0	0.7586	0.5034	177.60	69.4	443.0
0.61	0.1919	469.50	286.2	0.6485	0.4566	214.2	72.0	559.5
0.55	0.1551	580.0	319.0	0.5782	0.4231	245.5	73.5	670.0
0.50	0.1276	705.5	352.8	0.5211	0.3935	277.6	75.2	795.5
0.40	0.0811	1110.0	444.0	0.4108	0.3297	365.9	78.1	1200.0
0.30	0.0453	1985	595	0.3045	0.2592	514	81.0	2075
0.28	0.0395	2279	638	0.2837	0.2442	556	82	2369
0.26	0.0340	2646	688	0.2629	0.2289	606	82	2736
0.259	0.0337	2670	692	0.2619	0.2282	610	82	2760
0.20	0.0201	4475	895	0.2013	0.1812	811	84	4565
0.15	0.0113	7960	1194	0.1506	0.1393	1110	84	8050
0.14	0.0098	9190	1287	0.1405	0.1307	1200	87	9280

TABLE 2

$\frac{T}{w} = 134.5$

$X' = 42.00'$

X	A	B	DIFF	90-ø	COTAN	SCALE	$\frac{dF}{dx}$
0	45.00	45.00	0	25	2.24	2.5	5.60
1	47.8	42.10	5.7	25	2.24	2.5	5.60
2	50.7	39.6	11.1	24	2.36	2.5	5.80
4	57.7	34.8	22.9	22.1	2.46	2.5	6.15
6	65.9	30.5	35.4	21.3) 21.2) 21.2	2.58	2.5	6.45
8	75.7	26.8	48.9	20.9	2.62	2.5	6.55
10	86.0	23.4	62.6	18.6	2.97	2.5	7.42
12	100.0	20.5	79.5	16.0	3.48	2.5	8.70
14	116	17.8	98	14.1	3.98	2.5	9.85
16	135	15.4	120	12.3	4.59	2.5	11.48
18	156	13.2	143	63.0	,510	25	12.78
20	183	11.3	172	57.2	.645	25	16.15
22	218	9.7	209	52	.781	25	19.80
24	262	8.1	254	46.2	.96	25	24.05
26	315	7.7	308	40.7	1.16	25	29.0
28	370	5.4	365	34.0	1.48	25	37.0
30	469.0	4.2	465	27.6	1.91	25	47.7
32	575	3.2	572	19.1	2.88	25	72.0
34	750	2.4	745	13.2	4.26	25	106.9
35	905	2.0	903	58.0	.625	250	156.1
36	1065	1.6	1064	6.9	8.25	25	206
37	1285	1.2	1286	44.6	1.012	250	253.4
38	1580	0.9	1579	35.0	1.43	250	358.0
39	2000	0.6	2000	28.0	1.88	250	470.0
40	2670	0.3	2670	17.8	3.11	250	777
41	3800	0.1	3800	8.1	7.03	250	1758.0
42	10000	0.0	10000	1.5	38	250	9550
43	Infinite	0	Infinite				

TABLE 3 - I

Wind Angle	Side	Section	p	Number of Sections	m	Σp	y_b	$\bar{y}$
30°	1	1	+ .45	0	0			
		2	.42	1	+ .42			
		3	.37	2	.74			
		4	.30	3	.90			
		5	.24	4	.96			
		6	.17	5	.85			
		7	.10	6	.60			
		8	.01	7	.07			
		9	-.07	8	-.56			
		10	-.16	9	-1.44			
			+1.73		+2.54	+1.73	1.47	3.03
30°	2	1	+ .60	0	0			
		2	.60	1	.60			
		3	.60	2	1.20			
		4	.60	3	1.80			
		5	.60	4	2.40			
		6	.60	5	3.00			
		7	.60	6	3.60			
		8	.60	7	4.20			
		9	.60	8	4.80			
		10	.60	9	5.40			
			6.00		27.00	+6.00	4.5	0.0
30°	3	1	+ .45	0	0			
		2	.37	1	+ .37			
		3	.29	2	.58			
		4	.20	3	.60			
		5	.12	4	.48			
		6	.04	5	.20			
		7	- .03	6	- .18			
		8	- .10	7	- .70			
		9	- .17	8	-1.36			
		10	- .23	9	-2.07			
			+ .94		-2.08	+0.94	-2.215	6.715

TABLE 3 - II

Wind Angle	Side	Section	p	Number of Sections	m	Σp	y_b	$\bar{y}$
30°	4	1	+ .60	0	0			
		2	.60	1	+ .60			
		3	.60	2	1.20			
		4	.56	3	1.68			
		5	.45	4	1.80			
		6	.45	5	2.25			
		7	.45	6	2.70			
		8	.45	7	3.15			
		9	.45	8	3.60			
		10	.45	9	4.05			
			5.06		21.03	+5.06	4.14	0.46
45°	1	1	+ .76	0	0			
		2	.71	1	+ .71			
		3	.64	2	1.28			
		4	.56	3	1.68			
		5	.47	4	1.88			
		6	.38	5	1.90			
		7	.30	6	1.80			
		8	.20	7	1.40			
		9	.12	8	0.96			
		10	.02	9	0.18			
			4.16		11.79	4.16	2.83	1.67
45°	2	1	+ .60	0	0			
		2	.60	1	.60			
		3	.60	2	1.20			
		4	.60	3	1.80			
		5	.60	4	2.40			
		6	.60	5	3.00			
		7	.60	6	3.60			
		8	.60	7	4.20			
		9	.60	8	4.80			
		10	.60	9	5.40			
			6.00		27.00	+6.00	4.5	0.0

TABLE 3 - III

Wind Angle	Side	Section	p	Number of Sections	m	Σp	y_b	$\bar{y}$
45°	3	1	+ .76	0	0			
		2	.55	1	+0.55			
		3	.33	2	.66			
		4	.18	3	.54			
		5	.14	4	.56			
		6	.10	5	.50			
		7	.06	6	.36			
		8	.03	7	.21			
		9	.00	8	.00			
		10	.00	9	.00			
			2.15		3.38	2.15	1.57	2.93
45°	4	1	+ .60	0	0			
		2	.60	1	+ .60			
		3	.57	2	1.14			
		4	.55	3	1.65			
		5	.55	4	2.20			
		6	.55	5	2.75			
		7	.55	6	3.30			
		8	.55	7	3.85			
		9	.55	8	4.40			
		10	.55	9	4.95			
			5.62		24.84	5.62	4.42	0.08
60°	1	1	+ .86	0	0			
		2	.83	1	+ .83			
		3	.80	2	1.60			
		4	.76	3	2.28			
		5	.70	4	2.80			
		6	.62	5	3.10			
		7	.55	6	3.30			
		8	.45	7	3.15			
		9	.32	8	2.56			
		10	.27	9	1.98			
			6.11		21.60	6.11	3.54	0.96

TABLE 3 - IV

Wind Angle	Side	Section	p	Number of Sections	m	Σp	y_b	$\bar{y}$
68	2	1	+ .56	0	0			
		2	.55	1	+ .55			
		3	.55	2	1.10			
		4	.55	3	1.65			
		5	.55	4	2.20			
		6	.54	5	2.70			
		7	.54	6	3.24			
		8	.53	7	3.61			
		9	.51	8	4.08			
		10	.50	9	4.50			
			5.38		23.65	5.38	4.40	0.10
60°	3	1	+ .86	0	0			
		2	.24	1	+ .24			
		3	.03	2	.06			
		4	.00	3	.00			
		5	.00	4	.00			
		6	.00	5	.00			
		7	.00	6	.00			
		8	.00	7	.00			
		9	.00	8	.00			
		10	.00	9	.00			
			1.13		.30	1.13	0.266	4.23
60°	4	1	+ .50	0	0			
		2	.50	1	+0.50			
		3	.50	2	1.00			
		4	.50	3	1.50			
		5	.50	4	2.00			
		6	.50	5	2.50			
		7	.50	6	3.00			
		8	.50	7	3.50			
		9	.50	8	4.00			
		10	.50	9	4.50			
			5.00		22.50	5.00	4.50	0.0

TABLE 4 - I

Wind Angle	Force Name	Side	<p	A	y	pA or pAy	Total	F
30°	T	1	1.73	62852				
		4	5.03	62852		42650		
		2	6.00	46312				
		3	0.94	46312		32,100	74,750	2,755,000
	L		1.02	7360		7,500	7,500	276,200
	M	1	1.73	62852	3.03	2,725,000		
		4	5.03	62852	0.46	1,210,000		
		2	6.00	46312	0	0		
		3	0.94	46312	6.72	2,420,000	6,355,000	234,500,000
45°	T	1	4.16	65852				
		4	5.62	65852		61,450		
		2	6.00	46312				
		3	2.15	46312		37,750	99,200	3,657,000
	L		0.90	7360		6,620	6,620	244,000
	M	1	4.16	65852	1.67	3,615,000		
		4	5.62	65852	0.08	234,000		
		2	6.00	46312	0	0		
		3	2.15	46312	2,93	2,412,000	6,261,000	230,900,000
60°	T	1	6.11	65852				
		4	5.00	65852		69,950		
		2	5.38	46312				
		3	1.13	46312		30,150	100,100	3,690,000
	L		0.52	7360		3,825	3,825	141,000
	M	1	6,11	65852	0.96	3,055,000		
		4	5.00	65852	0	0		
		2	5.38	46312	0.10	206,000		
		3	1.13	46312	4.23	1,830,000	5,091,000	187,700,000
90°	T	1	8	62852				
		4	4	62852		75,500		
		2	5	46312				
		3	-2	46312		13,890	89,390	3,290,000
	L		0					0
	M				0			0

TABLE 5

WIND LOAD TABULATION @ 45°, 120 MPH

T	Sect.	Side 1	Side 2	Side 3	Side 4	p_s	$p_s x A_s$	P_s
Dist. from center 372.15	1	.76	+.60	+.76	.60	1.36 1.36	8550 6300 14850	548000
289.45	2	+.71	+.60	+.55	+.60	1.31 1.15	8240 5330 13570	500000
206.75	3	+.64	+.60	+.33	+.57	1.21 0.93	7610 4310 11920	440000
124.05	4	+.56	+.60	+.18	+.55	1.11 0.78	6980 3610 10590	390000
41.35	5	+.47	+.60	+.14	+.55	1.02 0.74	6410 3425 9835	362200
41.35	6	+.38	.60	.10	.55	.93 .70	5840 3240 9080	334500
124.05	7	+.30	.60	.06	.55	.85 .66	5340 3055 8395	309000
206.75	8	+.20	.60	+.03	+.55	.75 .63	4710 2920 7630	281200
289.45	9	+.12	+.60	.0	+.55	.67 .60	4210 2780 6990	257500
372.15	10	.02	+.60	+.0	+.55	+.57 +.60	3580 2780 6360	234500
							Total	3656900
L						+.90	6620	2.44×10^5

TABLE 6

$\psi = 45^\circ$
$T = 3.657 \times 10^6$
$L = 2.44 \times 10^5$
$M = 230.9 \times 10^6$

3" cast steel chain
standard assembly
Proof Load - 495,000#
Break Load - 693,000
Weight - 72.5 lb/ft

$T_1 = 5.04 \times 10^4$
$L_1 = 3.365 \times 10^3$
$M_1 = 3.185 \times 10^6$

1	2	3	4	5	6	7	8	9
Chain	F_1 $F_1 = \frac{P}{N}$	X_1	$f'(x_1)$	Δx_1 $\Delta x_a = \frac{M y_a}{f'(x_1) I_y}$	x_2	F_2	$f'(x_2)$	Δx_2 $\Delta x_n = \frac{\Delta F}{\Sigma f'(x_2)}$
a-1,2	3600	40.88	1700	+.6750	41.56	5650	4400	-.19
a-3,4	3600	40.88	1700	+.62	41.50	5370	3800	-.19
b-1,2	3600	40.88	1700	+.53	41.41	4930	3500	-.19
b-3,4	3600	40.88	1700	+.48	41.36	4700	3300	-.19
c-1,2	3600	40.88	1700	+.39	41.27	4400	2700	-.19
c-3,4	3600	40.88	1700	+.33	41.21	4320	2500	-.19
d-1,2	3600	40.88	1700	+.24	41.12	4070	2200	-.19
g-3,4	3600	40.88	1700	-.24	40.64	3290	1400	-.19
h-1,2	3600	40.88	1700	-.33	40.55	3180	1200	-.19
h-3,4	3600	40.88	1700	-.39	40.49	3100	1100	-.19
i-1,2	3600	40.88	1700	-.48	40.40	3020	1100	-.19
i-3,4	3600	40.88	1700	-.53	40.35	2980	1100	-.19
j-1,2	3600	40.88	1700	-.62	40.26	2890	1000	-.19
j-3,4	3600	40.88	1700	-.68	40.20	2830	900	-.19
Totals						-54730 50400 - 5670	30200	
L-1,2	1683	38.25	360	+.16	38.41	1750	390	-.01
L-3,4	1683	38.25	360	-.16	38.09	1620	345	-.01
Totals						-3370 +3365 - 5	735	

TABLE 6 (Cont'd)

10 x_3	11 F_3	12 y_1	13 M_3 $(F_3-3500)(y)$	14 $f'(x_3)$	15 y^2	16 $f'(x_3)\cdot y^2$ $x10^{-5}$	17 Δx_3 $\frac{\Delta x_a \Sigma M y_a}{\Sigma f'(x_3) y^2}$	18 x^4
41.37	4700	389.5	467500	3200	151710	4850	+.0805	41.45
41.31	4550	357.5	368000	3000	127806	3834	+.07	41.38
41.22	4320	306.5	251500	2500	93942	2349	+.06	41.28
41.17	4150	274.5	178500	2300	75350	1733	+.06	41.23
41.08	3980	223.5	107500	2200	49952	1100	+.05	41.13
41.02	3900	191.5	76500	2000	36672	733	+.04	41.06
40.93	3720	140.5	31000	1800	19740	356	+.03	40.96
40.45	3070	140.5	60500	1100	19740	217	-.03	40.42
40.36	2980	191.5	99500	1050	36672	385	-.04	40.32
40.30	2930	223.5	127500	1000	49952	500	-.05	40.25
40.21	2850	274.5	173000	920	75350	693	-.06	40.15
40.16	2780	306.5	220500	860	93942	807	-.06	40.10
40.07	2710	357.5	282500	840	127806	1071	-.07	40.00
40.01	2680	389.5	319000	800	151710	1212	-.08	39.93
Totals			2763000		1110344	19840		
38.40	1740	95.0		390	9025	35	+.02	38.42
38.08	1620	95.0		345	9025	31	-.02	38.06
Totals	120 x	95 =	11400 2763000 -2774400 +3185000 411600		18050 1128394	66 19906		

TABLE 6 (Cont'd)

19	20	21	22	23	24	25	26	27
F_4	$f'(x_4)$	Δx_4 $\frac{\Sigma \Delta F}{\Sigma f'(x)}$	x_5	F_5	y	M_5	$f'x_5$	y_2
5040	3500	+.0167	41.47	5110	-389.5	627000	3700	515710
4750	3200	+.02	41.40	4870	-357.5	489500	3300	127806
4430	2700	+.02	41.30	4500	-306.5	306500	2900	93942
4330	2500	+.02	41.25	4390	-274.5	244500	2600	75350
4100	2300	+.02	41.15	4130	-223.5	141000	2300	49952
3950	2200	+.02	41.08	3990	-191.5	94000	2100	36672
3750	1800	+.02	40.98	3780	-140.5	39500	1800	19740
3050	1100	+.02	40.44	3070	+140.5	60500	1100	19740
2950	1000	+.02	40.34	2970	191.5	101500	1050	36672
2880	940	+.02	40.27	2880	223.5	138500	980	49952
2770	880	+.02	40.17	2790	274.5	195000	900	75350
2740	860	+.02	40.12	2760	306.5	226500	860	93942
2640	800	+.02	40.02	2680	357.5	293000	800	127806
2610	760	+.02	39.95	2620	389.5	342500	780	151710
-49990	24540			50540		3299500		
50400								
+ 410								
1750	390	0.0	38.42	1750	95.0		390	9025
1610	340	0.0	38.06	1610	95.0		340	9025
-3360	730			140 x	95 =	13500		
+3365						-3313000		
+ 5						+3185000		
						- 128000		

TABLE 6 (Cont'd)

28 $f(x_5)y_5 \times 10^5$	29 $x_5 \frac{\Sigma \Delta M y_a}{\Sigma f(x_5) y^2_n}$	30 x_6	31 F_6	32 M_6	33 $\frac{Fxw}{1000}$ (kips)
5610	-.023	41.45	5040	600000	365.5
4210	-.02	41.38	4750	446000	345.5
2722	-.02	41.28	4430	285000	321.5
1958	-.02	41.23	4330	228000	314.0
1150	-.01	41.14	4130	141000	299.5
770	-.01	41.07	3980	92000	288.5
356	-.01	40.97	3770	38000	273.5
217	+.01	40.45	3070	60500	222.5
385	+.01	40.35	2980	99500	216.0
480	+.01	40.28	2900	134000	210.0
678	+.02	40.19	2820	186500	204.0
806	+.02	40.14	2780	220500	201.5
1021	+.02	40.04	2700	286000	196.0
1181	+.02	39.97	2630	339000	191.0
21544				3156000	3649.0
			-50310		
			+50400		
			+ 90		
35	-.01	38.41	1750		127.0
31	+.01	38.07	1610		117.0
66			-3360	13500	
21610			+3365	-3169500	244.0
			+ 5	+3185000	
				15500	

TABLE 7 - I

Moment of Inertia of Wing Wall

Member & Location	No	Unit Area -in^2	Total Area-in^2	Dist. to ℄ - ft.	Area x Dist.^{2} -in^{2}ft^2	I_o-in^4
Deck Pl-11/16"x18'-9 3/16"	1	154.8	154.8	0	0	624219
Safety Deck-1/2" x 20'-0"	1	120.0	120.0	0	0	576000
Bottom Pl-15/16" x 18' - 9 5/32"	1	211.0	211.0	0	0	892116
WingWall Pl -11/16" x 6'-0"	2	49.5	99.0	10	9900	4
-9/16" x5'-11 3/8"	2	40.1	80.2	10	8020	3
-1/2" x 6'-0"	2	36.0	72.0	10	7200	2
-7/16" x6'-0"	2	31.5	63.0	10	6300	2
-7/16" x6'-0"	2	31.5	63.0	10	6300	2
-1/2" x6'-0"	2	36.0	72.0	10	7200	2
-1/2" x6'-0"	2	36.0	72.0	10	7200	2
-9/16" x5'-11 3/8"	2	40.1	80.2	10	8020	3
-13/16" x6'-0"	2	58.5	117.0	10	11700	5
14" WF 314#-Cut 8½" Deep-atDeck	2	45.9	91.8	10	9180	1630
14" WF 211#-Cut 7" Deep-at Bottom	2	30.0	60.0	10	6000	1028
Wing Deck Stiff- 12" [s25 (Cut)	2	3.08	6.16	8	394.2	5
	2	3.08	6.16	6	221.8	5
	2	3.08	6.16	4	98.6	5
	2	3.08	6.16	2	24.6	5
Safety Deck Stiff.- 12" [s25 (Cut)	2	3.08	6.16	8	394.2	5
	2	3.08	6.16	6	221.8	5
	2	3.08	6.16	4	98.6	5
	2	3.08	6.16	2	24.6	5

TABLE 7 - II

Moment of Inertia of Wing Wall

Member & Location	No	Unit Area -in^2	Total Area-in^2	Dist.to ℄ -ft.	Area x Dist.^{2} -in^{2}ft^2	I_o-in^4
6"x6"x1/2"∠s at Safety Deck	2	5.75	11.5	9.84	1113.5	40
Bottom Stiff.- 15" [s33.9 (Cut)	2	4.35	8.7	8	556.8	8
	2	4.35	8.7	6	313.2	8
	2	4.35	8.7	4	139.2	8
	2	4.35	8.7	2	34.8	8
Side Pl Stiff.- 8" [s18.75	6	5.49	33.01	9.64	3066.7	262
-12" [s 25 (Cut)	12	3.08	37.0	9.47	3318.2	1728
-12" [s 25 (Cut)	16	3.08	49.3	9.47	4421.3	2304
-12" [s 25 (Cut)	12	3.08	37.0	9.47	3318.2	1728
- 8" [s 18.75	6	5.49	33.0	9.64	3066.7	262
Totals					107847.0	2131414
					14801.5 122648.5	÷ 144 = 14801.5

TABLE 7 - III

Moment of Inertia of Wing Wall Splice

Member & Location	No	Unit Area	Total Area	Dist. to ℄	Area x (Dist)^2	I_o-in^4
1 1/4" Pl at Wing Deck	2	15.0	30.0	0	0	360
	4	15.0	60.0	1.25	90.8	720
	4	15.0	60.0	2.50	375	720
	4	15.0	60.0	3.75	1843.8	720
	4	15.0	60.0	5.00	1400	720
	4	52.50	210.0	7.50	11812.5	26666.7
1 1/4" Side Pl	8	81.25	650.0	10.0	65000	
1 1/4" Pl Under Side	4	15.0	60.0	0.625	23.5	720
	4	15.0	60.0	1.875	180.9	720
	4	15.0	60.0	3.125	585.9	720
	4	15.0	60.0	4.375	1148.4	720
	4	15.0	60.0	5.625	1898.4	720
	4	45.0	180.0	7.875	11162.8	19440
Totals					95522.0 367.7 95889.7	52947 ÷ 144 = 367.7

TABLE 8

COMPUTATIONS

WingWall Moments and Shears

Location	Name	Load	V	Dist.	VxDist.	M
389.5	a-1,2	365.5	0	0	0	950
372.15	W-1	-548.0	365.5	17.35	6340	7290
357.5	a-3,4	345.5	-182.5	14.65	-2675	4615
306.5	b-1,2	321.5	163.0	51.00	8310	12925
289.45	W-2	-500.0	484.5	17.05	8260	21185
274.5	b-3,4	314.0	- 15.5	14.95	- 220	20965
223.5	c-1,2	299.5	298.5	51.00	15225	36190
206.75	W-3	-440.0	598.0	16.75	10015	46205
191.5	c-3,4	288.5	158.0	15.25	2410	48615
140.5	d-1,2	273.5	446.5	51.00	22770	71385
124.05	W-4	-390.0	720.0	16.45	11845	83230
41.35	W-5	-362.2	330.0	82.70	27290	110520
41.35	W-6	-334.5	- 32.2	82.70	- 2665	107855
124.05	W-7	-309.0	-366.7	82.70	-30325	77530
140.5	g-3,4	222.5	-675.7	16.45	-11115	66415
191.5	h-1,2	216.0	-453.2	51.00	-23095	43320
206.75	W-8	-281.2	-237.2	15.25	- 3615	39705
223.5	h-3,4	210.0	-518.4	16.75	- 8680	31025
274.5	i-1,2	204.0	-308.4	51.00	-15730	15295
289.45	W-9	-257.5	-104.4	14.95	- 1560	13735
306.5	i-3,4	201.5	-361.9	17.05	- 6160	7575
357.5	j-1,2	196.0	-160.4	51.00	- 8180	- 605
372.15	W-10	-234.5	35.6	14.65	510	- 95
389.5	j-3,4	191.0	-198.9	17.35	- 3450	- 3545
			- 7.9			

Moment caused by longitudinal chains:

(127.0-117.0) 95.0 = 950 ft. kips.

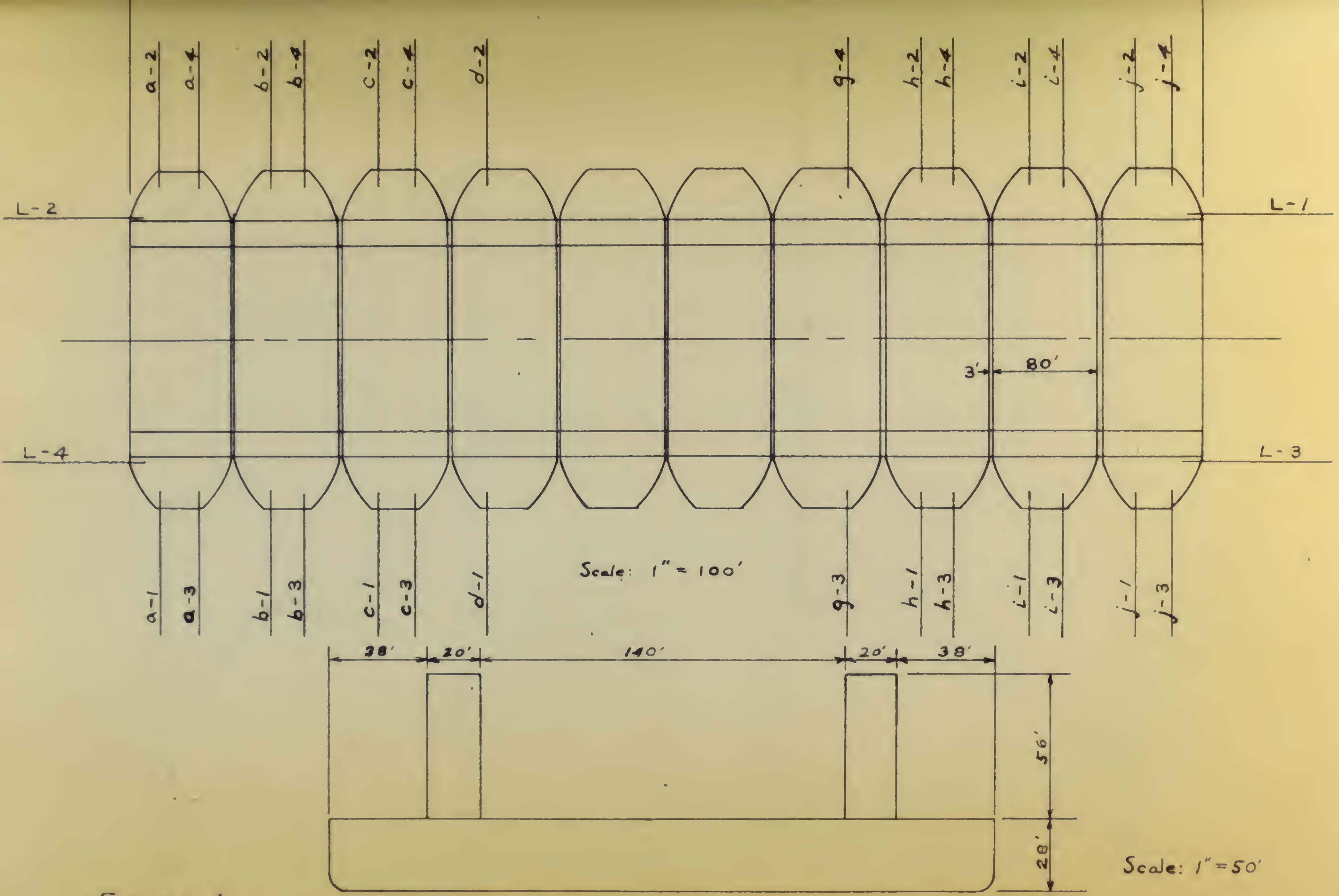


FIGURE 1

PLAN AND END ELEVATION OF 10 SECTION AFDB

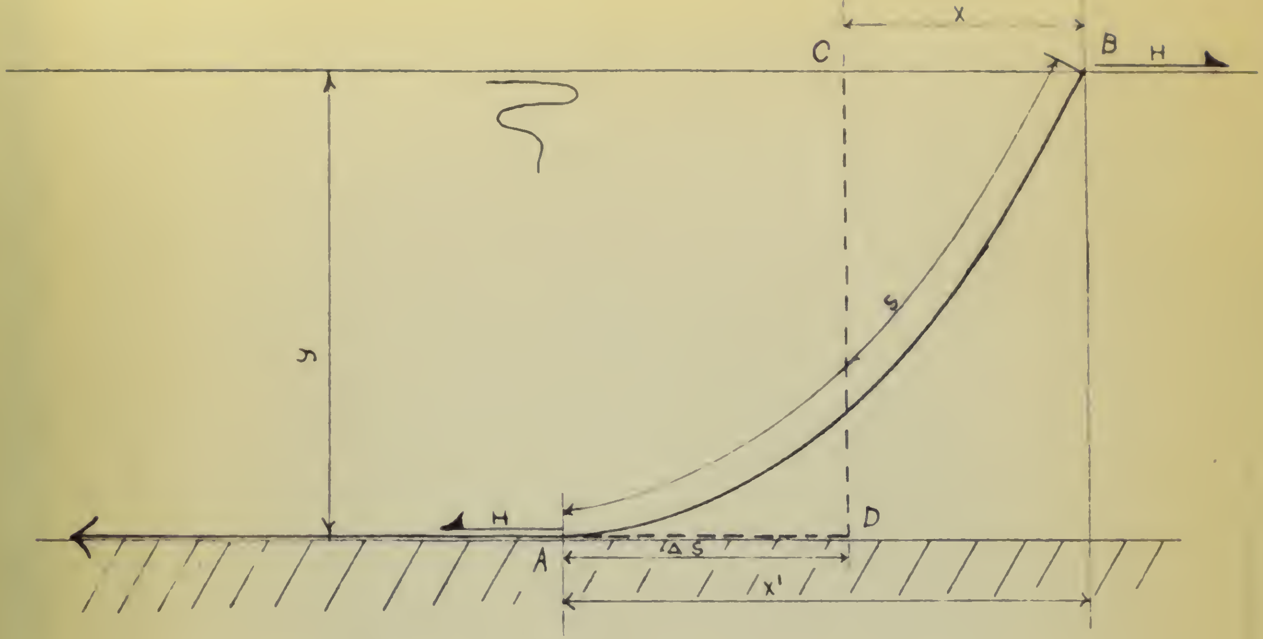


Figure 2.

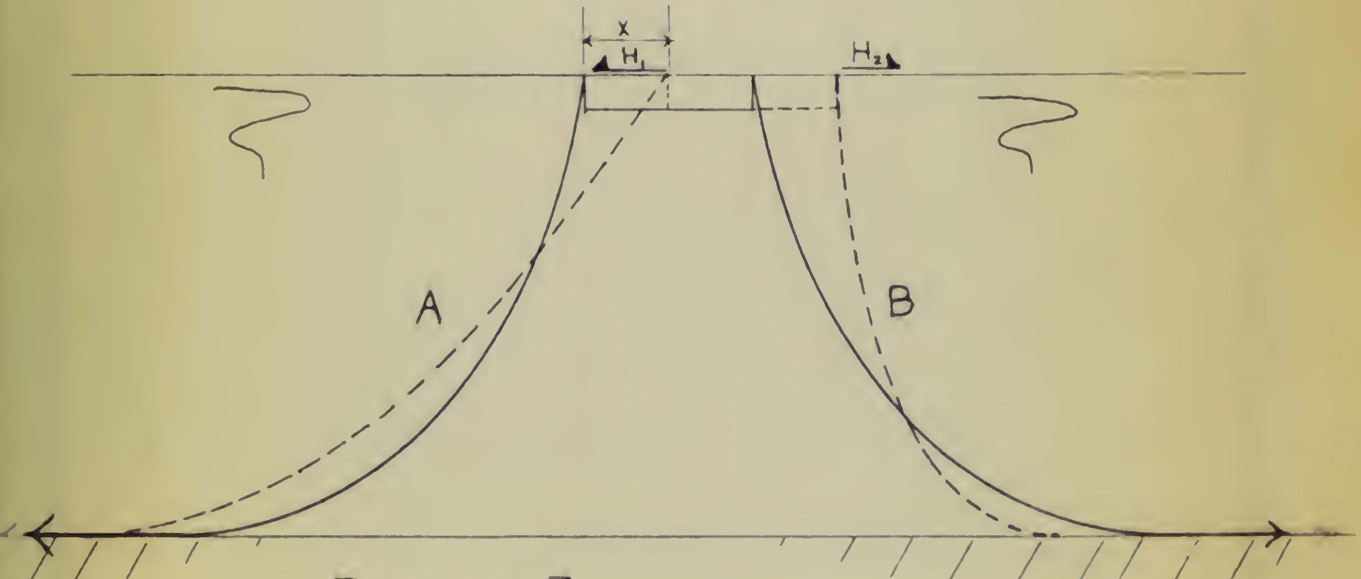


Figure 3.

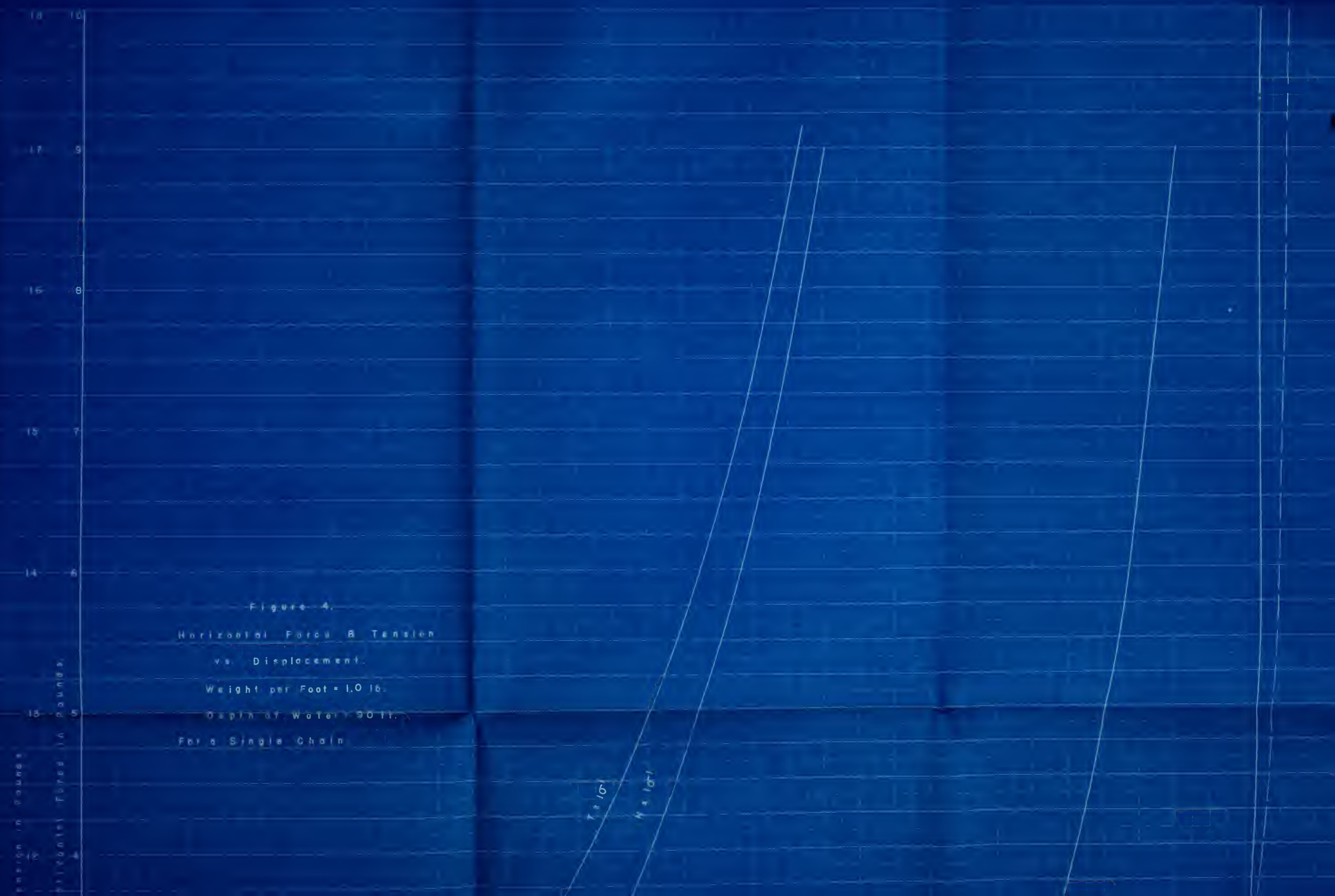


Figure 4.

Horizontal Force & Tension vs. Displacement.

Weight per Foot = 1.0 lb.

Depth of Water = 90 ft.

For a Single Chain

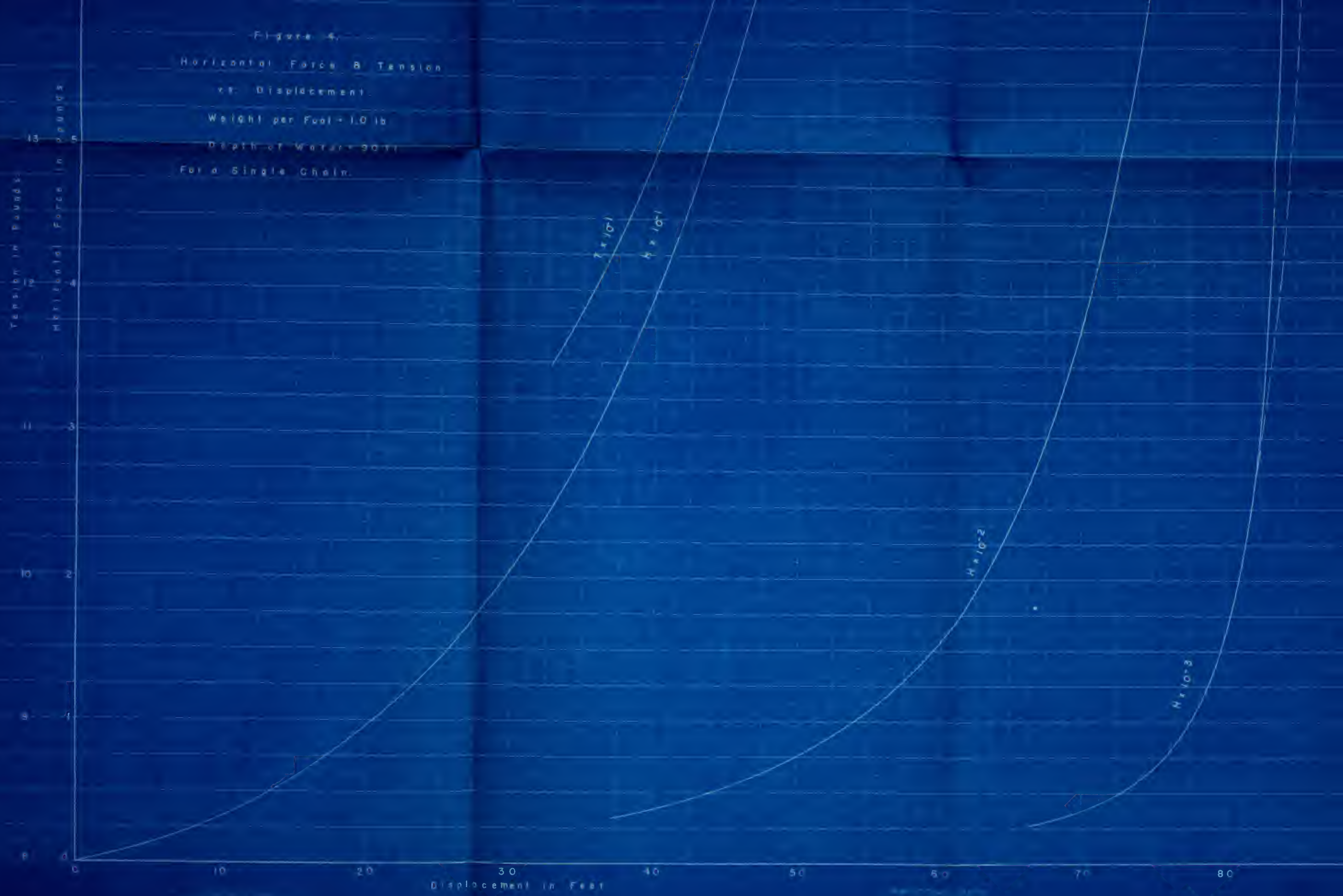


Figure 4.

Horizontal Force & Tension vs. Displacement

Weight per Foot = 1.0 lb

Depth of Water = 90 ft

For a Single Chain.

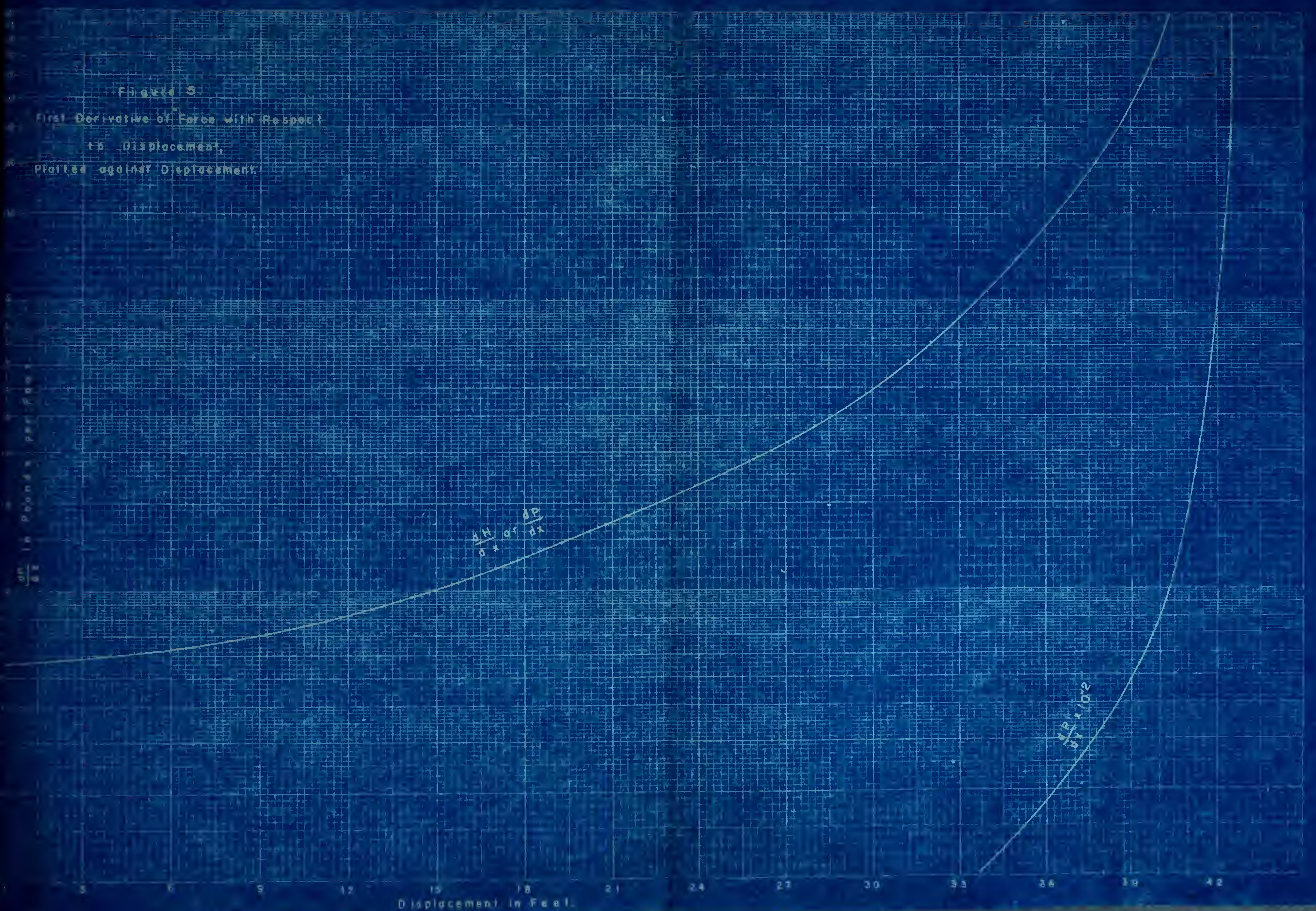
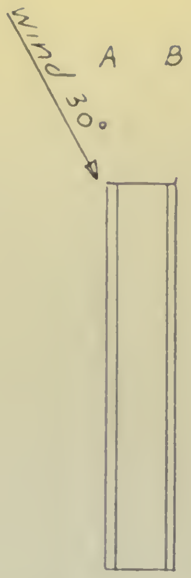


Figure 5.

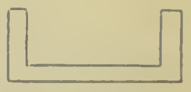
First Derivative of Force with Respect to Displacement, Plotted against Displacement.

10
9
8
7
6
5
4
3
in Pounds.

Figure 5
Horizontal Force vs. Displacement
Weight per Foot = unity
Initial Tension = 134.5 lb.
Depth of Water = 900 ft.
Chain Length = 700 ft.
For a Pair of Chains.



PLAN OF DOCK



CROSS SECTION

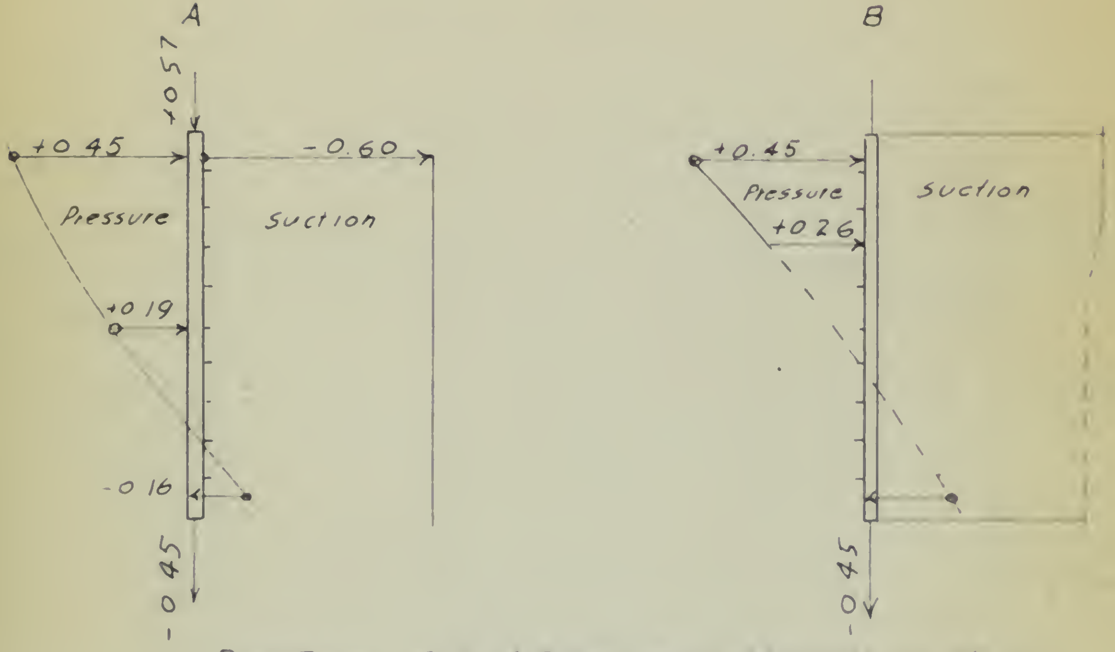
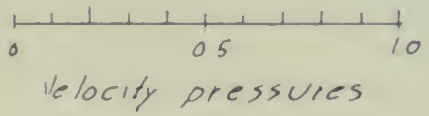
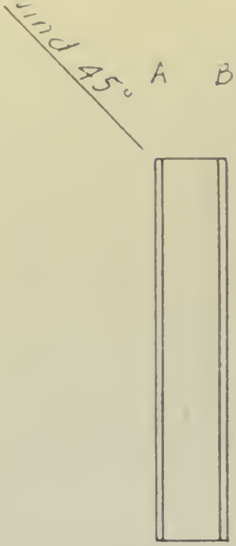


DIAGRAM FOR AVERAGE WIND PRESSURE ON WALLS
PLAN OF WALLS

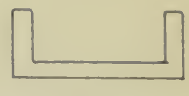
FIGURE 6



AFTER A AMIRIKIAN



PLAN OF DOCK



CROSS SECTION

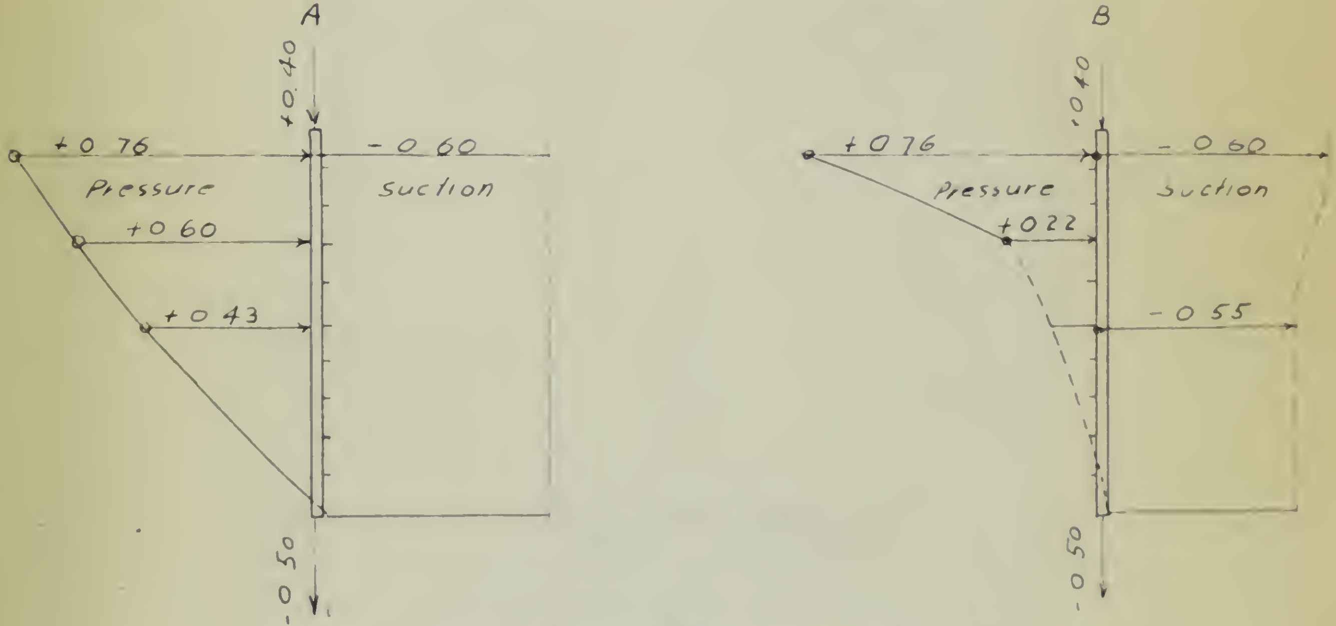
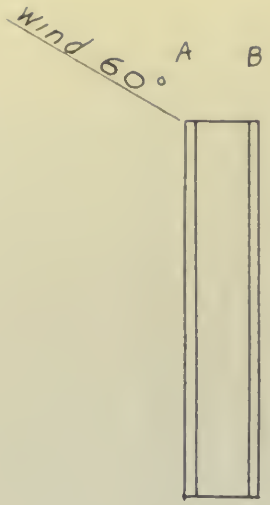


DIAGRAM FOR AVERAGE WIND PRESSURE ON WALLS
PLAN OF WALLS

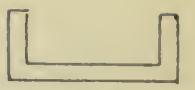
FIGURE 6

Velocity pressures

AFTER A AMIRIKIAN



PLAN OF DOCK



CROSS SECTION

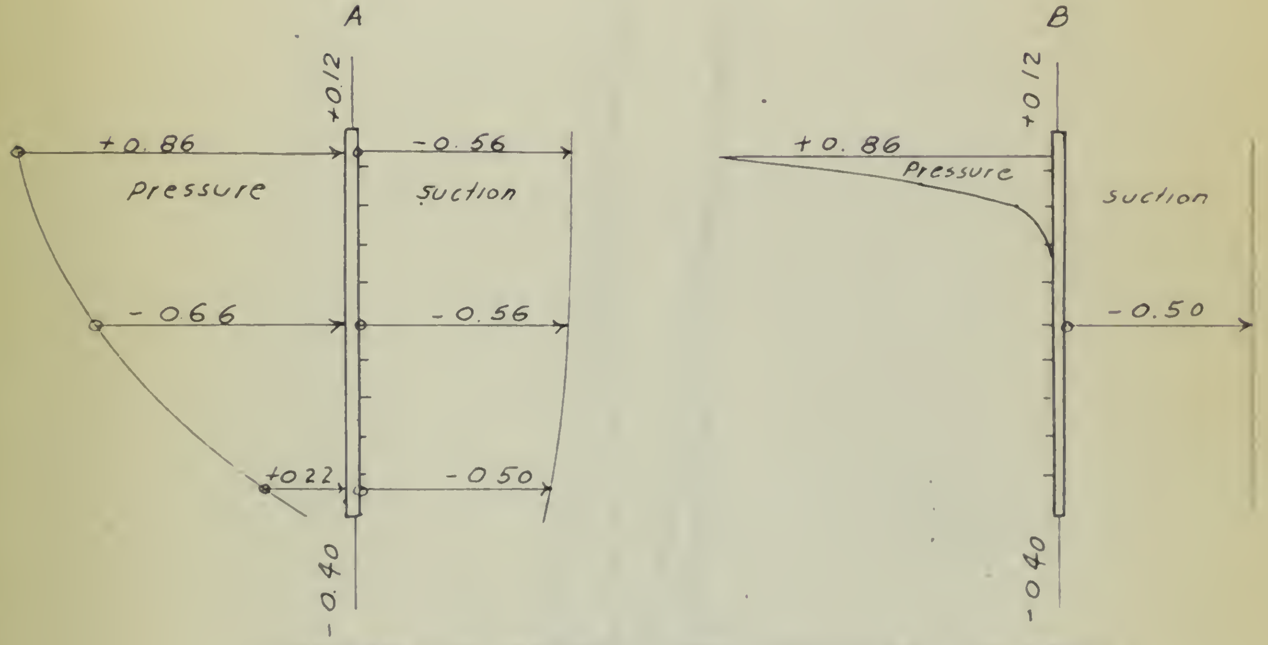
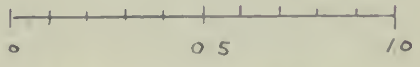


DIAGRAM FOR AVERAGE WIND PRESSURE ON WALLS
PLAN OF WALLS

FIGURE 6.



Velocity pressures

AFTER A AMIRIKIAN

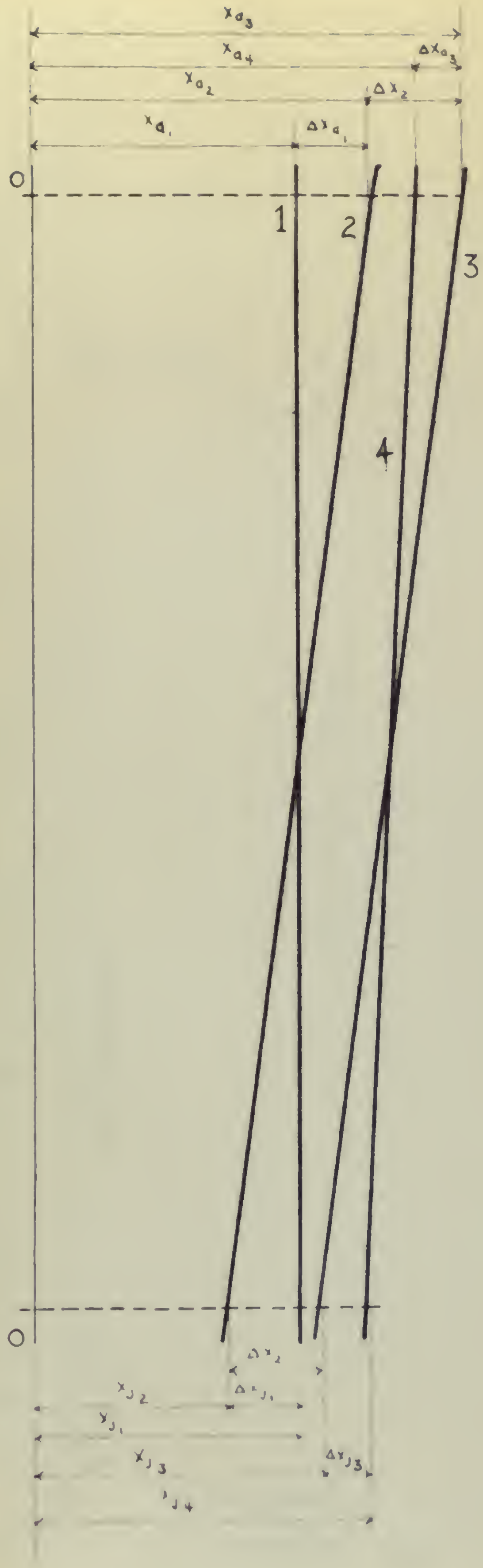
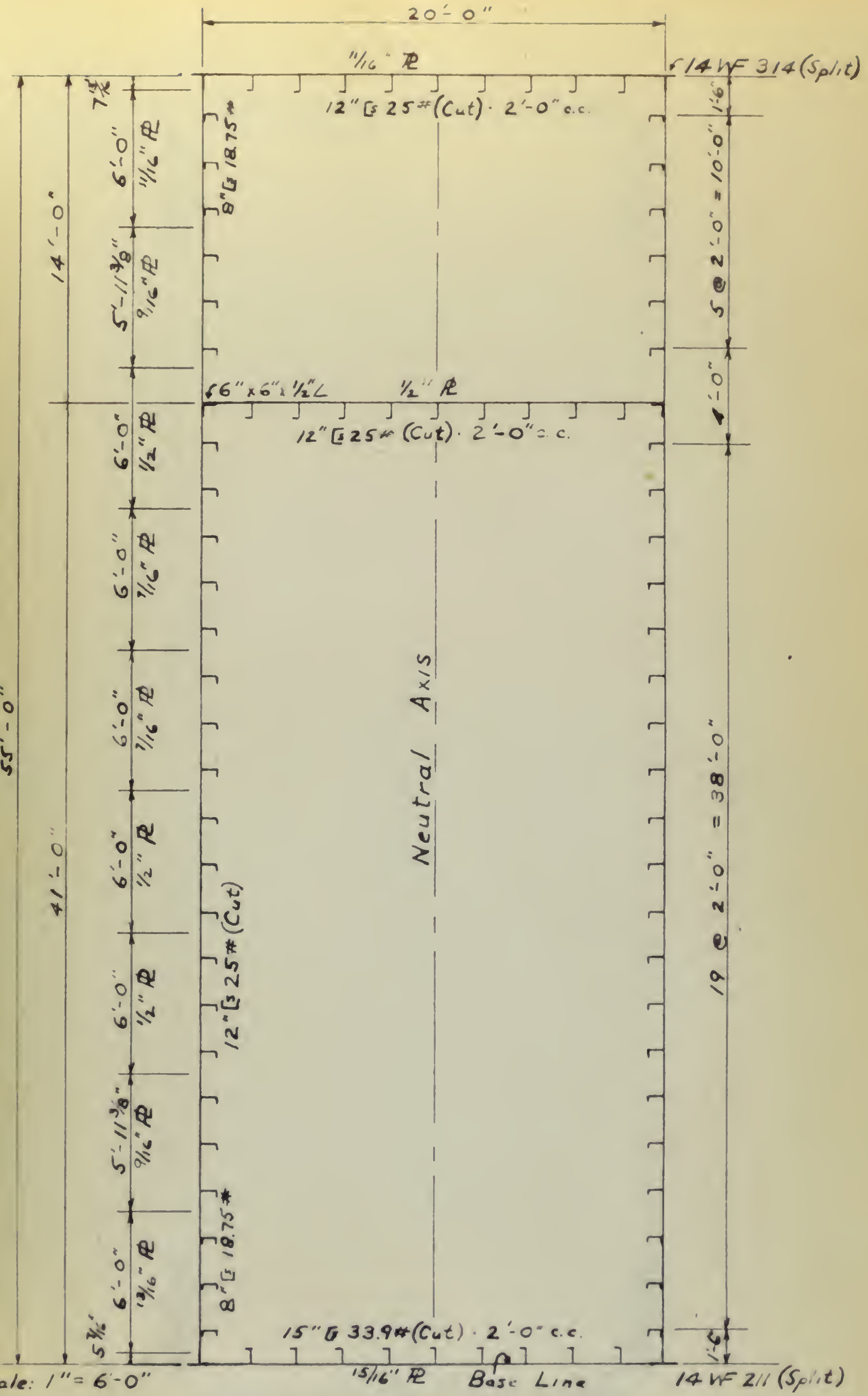

x_{a_3}
x_{a_4}
Δx_{a_3}
x_{a_2}
Δx_2
x_{a_1}
Δx_{a_1}
0
1
2
3
4
0
Δx_2
x_{J2}
Δx_{J1}
x_{J1}
x_{J3}
Δx_{J3}
x_{J4}

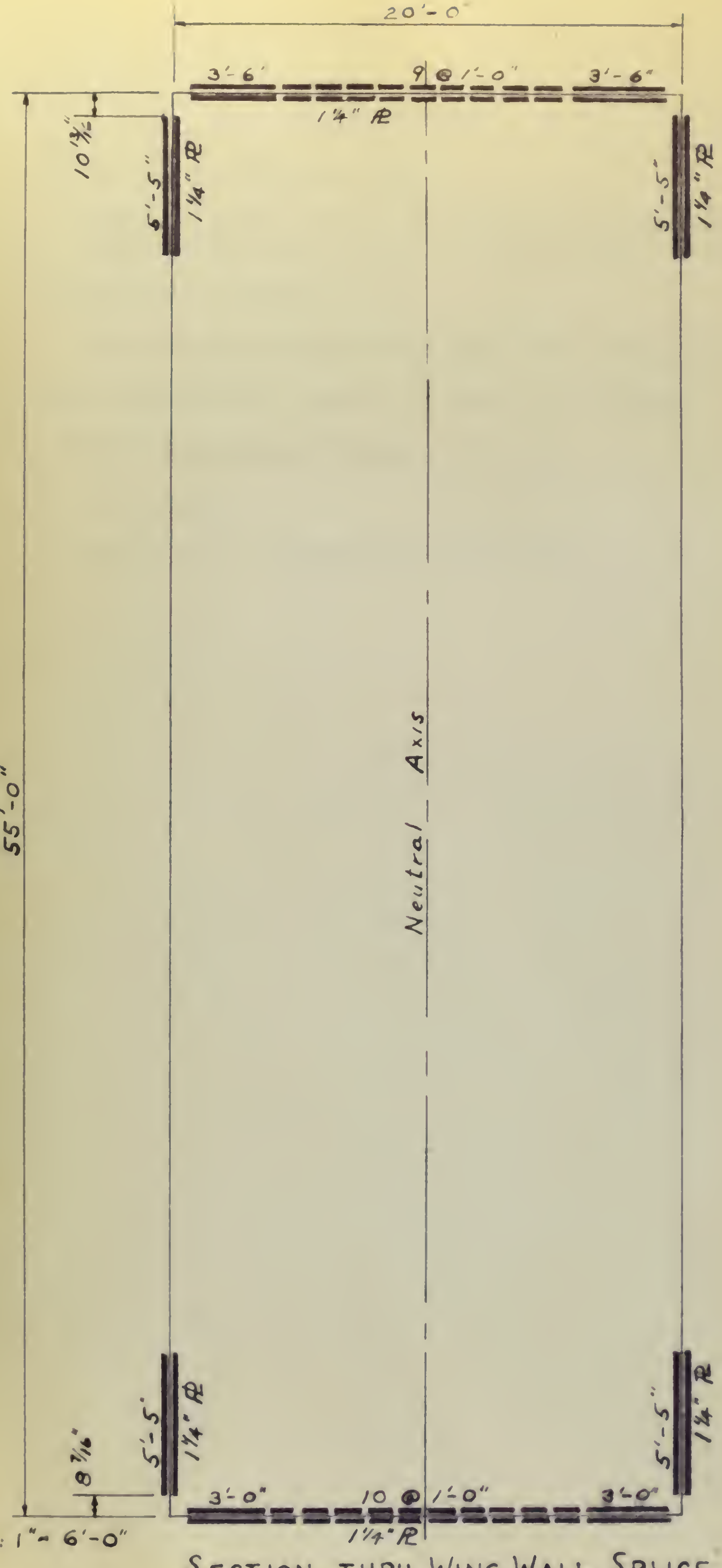
Figure 7.



Scale: 1" = 6'-0"

TYPICAL SECTION THRU WING WALL

FIGURE 8a



Scale: 1" = 6'-0"

FIGURE 8b

SECTION THRU WING WALL SPLICE

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